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Brain Stimulation Studies of Social Norm Compliance: Implications for Personality Disorders?

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Keywords
Brain stimulation · Ego-syntonic behavior · Personality disorders · Social norms · Transcranial direct current stimulation

Abstract
Several personality disorders involve pathological behaviors that violate social norms, commonly held expectations about what ought to be done in specific situations. These symptoms usually emerge early in development, are persistent and hard to treat, and are often ego-syntonic. Here I present some recent brain stimulation studies suggesting that pathological changes in different aspects of norm-compliant behavior reflect dysfunctions of brain circuits involving distinct prefrontal brain areas. One set of studies shows that transcranial direct current stimulation of the right lateral prefrontal cortex changes the behavioral sensitivity to social incentives for norm-compliant behavior. Crucially, social norm compliance in response to such incentives could even be increased during excitatory stimulation, demonstrating that the affected neural process is a biological prerequisite for appropriate reaction to social signals that trigger norm compliance. In another set of studies, we show that stimulation of a different (more dorsal) part of the right prefrontal cortex enhances honesty in a realistic setting where participants had the opportunity to cheat for real monetary gains. Interestingly, these stimulation-induced increases in both socially cued or purely voluntary norm compliance were not linked to changes in other aspects of decision-making (such as risk or impatience), and they did not reflect changes in beliefs about what is appropriate behavior. These results suggest that disorders of distinct brain circuits may causally underlie egosyntotic changes in norm-compliant behavior. This raises the tantalizing possibility that pathologies of norm-compliant behavior may be ameliorated by interventions targeting the function of these brain circuits.

Most aspects of our behavior are regulated by social norms, widely shared standards specifying how we ought to behave in a given situation (i.e., we should be fair, honest, punctual, etc.). Such norms exist in all known societies and are essential for peaceful and productive interactions [1, 2], since they minimize the need for explicit coordination between interaction partners. Prevailing social norms are usually known by all members of a given soci-

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ety; nevertheless, the power of norms to guide collective behavior erodes in the presence of just a few norm violators, since people follow social norms only if all others comply with it [3]. Norms are therefore often enforced by social sanction threats that are present both at an official level (e.g., legal codes specifying punishments for norm violations) and at the level of private peer-to-peer interactions (i.e., we know that other people will privately punish norm transgressions). The importance of credible sanction threats for preserving norm compliance is well documented through evolutionary, ethnographic, and laboratory studies [1–5].

While most people effortlessly comply with prevailing norms, some individuals routinely violate them and even break the law. These individuals are often diagnosed with a personality disorder, specifically if the corresponding behavior emerges early in life, is stable across time and hard to change by interventions, and is egosyntotic. Depending on the age of emergence, the diagnostic guidelines used, and other specifics of the symptomatology, the corresponding diagnoses may be antisocial personality disorder, dissocial personality disorder, psychopathy, sociopathy, or conduct disorder [6–8]. These disorders are common – with estimated prevalence ranging from 1 to 4% [9, 10] – and they are associated with significant financial and emotional costs to society and the affected individuals.

The origins of personality disorders associated with norm violations are debated. Both genetic predispositions [11, 12] and environmental factors [12–14] – such as prenatal influences and early childhood experiences – may play a role. However, it is largely unclear what psychological and/or biological mechanisms may be disrupted to bring about the symptoms of personality disorders. Perhaps even more importantly, very little is known about what psychological and/or biological processes should be targeted with external interventions to remedy pathological norm-violating behavior [15].

Here I describe the results of brain stimulation studies suggesting that two distinct aspects of pathological norm-violating behavior may reflect dysfunctions in brain circuits involving specific parts of the prefrontal lobe. Importantly, the experiments also suggest that these aspects of norm-violating behavior may – at least in principle – be ameliorated by interventions that target the excitability of these brain circuits.

In the first set of studies, young healthy participants faced a series of choices about how to allocate money between themselves (the proposer) and a fully anonymous interaction partner (the recipient). The roles of proposer and recipient were randomly determined, and the resulting payoffs were real, resulting in a salient fairness norm of a 50:50 split. In one condition measuring voluntary compliance with this norm, the proposed transfer was implemented without any possible consequences. In line with other findings [16], participants in this condition adhered to the fairness norm only weakly and transferred around 15% of the total amount [17]. However, in another condition, the recipient could react to the transfer by investing some of his/her own payoff to take money away from the proposer. This threat of a possible sanction led to a considerable increase in sanction-induced norm compliance (mean proposed transfers of around 45%). The magnitude of this behavioral reaction to the social sanction threat has been shown to correlate with increased neural activity in the right inferolateral prefrontal cortex (PFC) [18], leading us to hypothesize that this brain area may causally underlie the behavioral sensitivity to social incentives for compliance with social norms.

In our experiment, we employed transcranial direct current stimulation (tDCS) to experimentally increase (anodal tDCS) or decrease (cathodal tDCS) the excitability of this right inferolateral PFC (see blue circle in Fig. 1c). These activity modulations are implemented by means of weak electrical currents running between two electrodes, which change neural excitability in relatively large swathes of cortex, thereby facilitating or impeding neural activity under the electrodes elicited by behavioral control [19]. The stimulation indeed changed sanction-induced norm compliance, with transfer increases that were 30% higher (anodal) or 30% lower (cathodal) than in a placebo stimulation condition (Fig. 1a). Crucially, control experiments showed that these behavioral changes reflected a heightened sensitivity to social incentives for norm compliance rather than changes in the willingness to share money generally [17]. The increased transfers also did not relate to changes in risk-taking or cognitive abilities necessary to adequately react to the two conditions, demonstrating that the stimulation-induced changes reflect a specific mechanism for social norm compliance and that the tDCS, despite its limited spatial resolution, did not affect other aspects of behavioral control. Interestingly, the tDCS-elicited increase in sanction-induced norm compliance occurred without any change in the participants' beliefs or perceptions of the opponent reactions or the fairness norm itself (Fig. 1b). Thus, the pattern of results suggests that the stimulated prefrontal circuit causally controls the behavioral sensitivity to social incentives for norm-compliant behavior, in a manner that is not directly accessible to conscious report of the participants.

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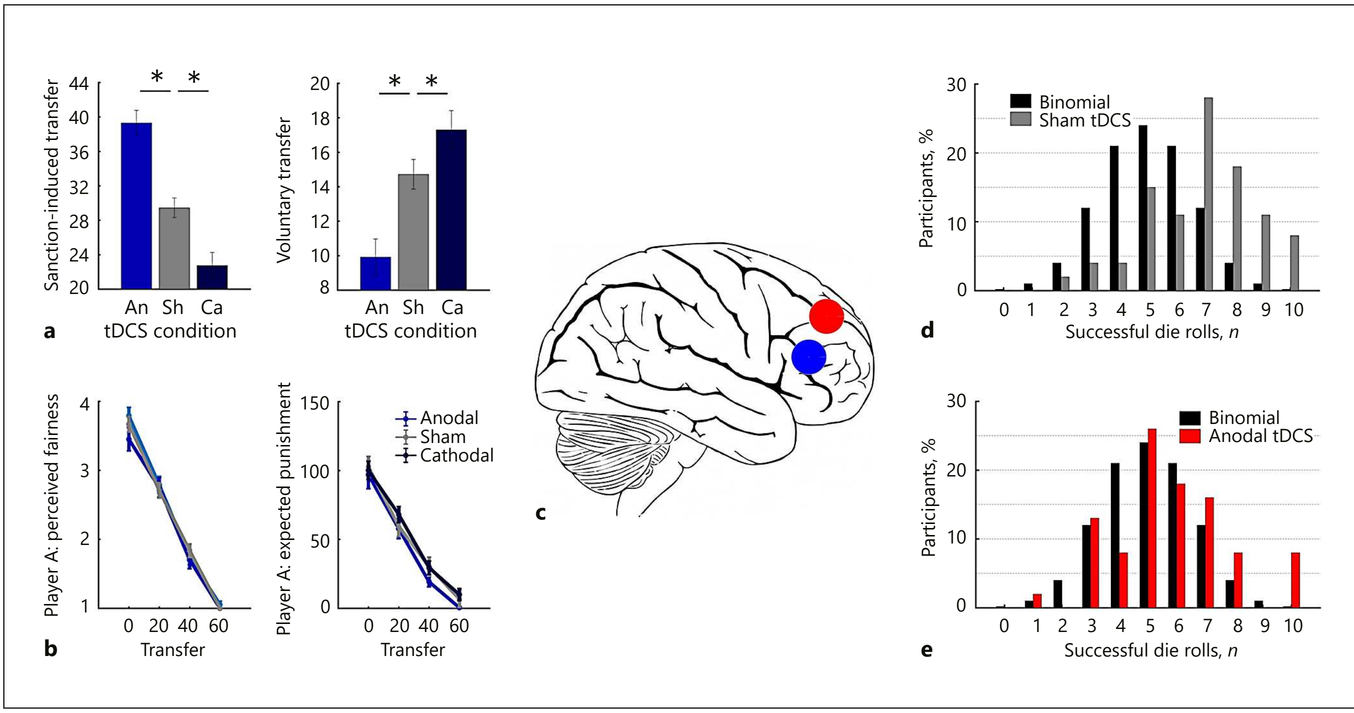

Fig. 1. Two prefrontal circuits for norm compliance. **a** Transcranial direct current stimulation (tDCS) over the blue-colored region in **c** leads to changes in norm compliance (compared to neurally ineffective sham tDCS) that are motivated by social incentives. When no social sanctions were present (right bar plot), excitatory anodal tDCS (An) decreased and inhibitory cathodal tDCS (Ca) increased voluntary compliance with the fairness norm. However, when social sanctions were present (left bar plot), excitatory anodal tDCS lead to higher transfers (more compliance) and inhibitory cathodal tDCS to lower transfers (less compliance). Please note that the circles are much smaller than electric fields elicited by tDCS, but that the effective resolution of neural excitability changes due to these fields may also depend on the presence of neural activity related to behavior, which can be much more focal. **b** The tDCS-induced changes in norm compliance were not accompanied by any changes in beliefs about what constitutes fair behavior (left line plot) or the possible consequences of norm transgressions (right line plot). **a**, **b** See Ruff et al. [17] for further information. **c** Schematic location of the 2 prefrontal tDCS target areas employed in the study by Ruff et al. [17] (blue circle) and Maréchal et al. [21] (red circle). **d** Participants with neurally ineffective sham tDCS over the red area in **c** lied substantially in the die-rolling game, as indicated by the shift towards implausibly high outcomes in the observed distribution of reported outcomes (in gray) compared to the statistically expected distribution for honest reporting (in black). **e** Honest reporting is increased in participants with excitatory anodal tDCS over the red area in **c**. Compared to the sham distribution in **d**, the observed distribution of reported outcomes in the anodal group (in red) is systematically shifted back towards the statistically expected distribution (in black). **d**, **e** See Maréchal et al. [21] for further information.

Our second set of experiments highlights that purely voluntary norm compliance, in the explicit absence of any social incentives, may require a brain circuit involving a different prefrontal area. These studies focused on honesty, a behavior that is purely motivated by the private determination to comply with this social norm (since lying is not evident to outside observers). We again employed tDCS, but now over a more dorsal area in the right PFC (see red circle in Fig. 1c) that had previously been shown to be activated when participants told the truth despite having the option to cheat for money [20]. We therefore hypothesized that this region and its interconnected structures may be involved in representing the motivation to remain honest in situations where this motive conflicts with the temptation to lie for financial benefit.

In the experiment, participants completed a series of tasks that they thought measured determinants of luck. One of these tasks offered them the opportunity to cheat in order to gain money. They rolled a die 10 times and entered the corresponding outcomes on a computer screen, which told them explicitly which 3 of the 6 possible outcomes was associated with a monetary gain. Participants therefore faced the temptation to misreport unsuccessful die outcomes, and they knew that such cheating could not be detected (since the die rolls were unobserved, and all outcomes were equally possible). However, analyzing the distribution of earnings across the different stimulation groups, we could statistically determine how the level of cheating was influenced by brain stimulation.

Participants in the group with placebo brain stimulation lied substantially (on 37% of all possible occasions; Fig. 1d), but this tendency to cheat was reduced by half (to 15%) during excitatory anodal tDCS (Fig. 1e). The tDCS-related increase in honesty was highly specific to situations where the honesty norm conflicted with the motivation for private monetary gain, as the tDCS affected neither purely financial choices (e.g., risky choices or choices with rewards given at different time points) nor choices between different moral motives (e.g., lying for someone else's benefits) [21]. Again, this stimulation effect on compliance with the honesty norm was not accompanied by changes in the perceptions of the social norm or the appropriateness of the behavior. Thus, in close similarity to the findings concerning sanction-induced norm compliance, our results suggest that the stimulated (different) circuit is a biological prerequisite for compliance with social norms, but now those that are motivated purely internally. Moreover, our results suggest that this circuit also operates in a way that is not consciously accessible to the decision-maker.

That PFC dysfunction may generally underlie symptoms of personality disorders has been proposed for a long time [22]. This general hypothesis concurs with the well-established role of PFC in the executive control of behavior [23] and with the time course of development of this brain structure that parallels the emergence of relevant symptoms [24]. Moreover, neuroimaging evidence already points to dysfunctions of both medial and lateral prefrontal circuits in personality disorders [25, 26]. However, our data demonstrate several important and more detailed aspects of this prefrontal involvement. First, they suggest that circuits involving distinct prefrontal areas may underlie selective disruptions of social norm compliance that need not be accompanied by more general behavioral deficits in nonsocial contexts (e.g., risk-taking, general impulsivity). Second, they suggest that these prefrontal circuits themselves are functionally specialized for norm-compliant behavior that is either motivated by social incentives (right inferolateral PFC) or purely internally (right dorsolateral PFC). Third, they show that these circuits operate in a fashion that is dissociated from explicit judgements about norms and appropriate behavior [see also 27, 28 for potentially convergent findings], which may form a basis for ego-syntonic norm-violating behaviors in various personality disorders. More generally, these findings suggest that overt behavior may reflect behavioral control by brain circuits that are distinct from other neural mechanisms involved in explicit knowledge and verbal reports about appropriate behavior, a point that may also be relevant for other psychological disorders (e.g., substance abuse and impulse control disorders). Finally, our results show that the behavioral functions of these circuits may, at least in principle, be enhanced by external interventions to enhance norm compliance.

The precise neuroanatomy of all structures involved in these circuits may have to be determined by future studies with combined brain stimulation and functional MRI [29]. In particular, it is unclear which interconnected brain areas may be involved in these circuits, and what their hemispheric lateralization and spatial extent are. Convergent evidence with studies employing brain imaging [30] and lesion methodology [31] may help to narrow down these candidate regions. Finally, translational studies are needed to establish how clinically useful our findings could be, what the duration of the induced tDCS effects is, and what interventions may best enhance the functions of these circuits. Nevertheless, our findings highlight two prefrontal brain processes that are promising candidate targets to better diagnose, ameliorate, or even prevent personality disorders marked by norm-violating behavior.

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